Army Research Laboratory

Technological Areas to Improve Soldier Decisiveness: Insights From the Soldier-System Design Perspective

by W. David Hairston, Jesse Chen, Michael Barnes, Ivan Martinez, Michael LaFiandra, Mary Binseel, Angelique Scharine, Mark Ericson, Barry Vaughan, Brent Lance, and Kaleb McDowell

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14. ABSTRACT
The Board on Army Science and Technology has commissioned a committee on "Making the Soldier Decisive on Future Battlefields" with the overarching goal of identifying areas where our dismounted Soldiers have the potential for overmatch capability, particularly when operating in small units, and the technologies that will aide in realizing an overmatch. To supplement this effort, this report discusses five high-potential areas of technology from the realm of the human dimension, considering the integrative nature between the Soldier and the systems with which they interact.
We first discuss technologies that show promise within the realm of training, by helping to better prepare the individual Soldier for potentially volatile situations, followed by a description of technologies for predicting a user's intent via physiological assessment techniques. Then we discuss improved human-robot interactions gained through recent advances in control design, yielding increased throughput of the total unit. Next is a description of some examples where sense-heightening capability will provide superior quality information to the Soldier. Finally, we illustrate how a novel "whole system" design approach can improve the impact of new technologies when fielded and conclude with a discussion of how all of these topics amplify an ideal pairing between user and technology.

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1. Overview

There is an increasing interest among Army strategists to emphasize the decisiveness of the Soldier as an operational element within small groups (e.g., squads) and individually within increasingly dynamic environments. While in the past much technology has focused on improving vehicles and devices for mounted operations, current warfare tactics are forcing our Soldiers to continue operations in a dismounted fashion, often in scenarios that are highly uncertain. In conjunction with this, the Board on Army Science and Technology has commissioned a committee on "Making the Soldier Decisive on Future Battlefields." The overarching goal of this group is to identify (1) areas where our dismounted Soldiers have the potential for overmatch capability, particularly when operating in small units, and (2) the technologies that will aide in realizing an overmatch.

This report includes five high-potential areas of technology from the realm of the human dimension, considering the integrative nature between the Soldier and the systems with which they interact. First, we discuss some technologies that can enhance the training realm, with the goal of helping to better prepare the individual Soldier for potentially volatile situations. This is followed by a description of technologies for predicting the intent of a user and methods for streamlining how information might be presented to them using physiological assessment techniques. Then we elaborate on advances in the design of how operators interact with robotic devices that could maximize the total human-machine efficiency, providing increased throughput of the total unit. Next is a description of examples where the total awareness of a situation can be improved by using sense-heightening capability to provide superior quality information to the Soldier. Finally, we discuss a novel approach to device design, incorporating a "whole system" philosophy that will improve the impact of new technologies when fielded and its relation to dismounted Soldiers who are often limited in mobility by the design of their equipment. While each issue relates to new physical technologies on the horizon, the key impact to creating an overmatch against adversaries lies in the relation between these technologies and the Soldier, creating the ideal pairing between the user and equipment.

2. Technologies to Enhance Soldier Training

Today's Soldiers must be able to train at the point of need, enhance their adaptability, and overcome mission barriers to be successful in future operational environments. Given the highly dynamic and potentially volatile nature of many urban conflicts, our Soldiers must be adaptable, critical thinkers with refined interpersonal skills. Present and future conflicts will require

Soldiers to execute a broader set of missions with rapidly changing tactics further compounded by limitations in time and resources to execute what is known as Full Spectrum Operations (FSO). In preparation, a number of documents and pamphlets describe the anticipated future operational environments (*1*) and emphasize how the complexity of future operations will require the Army to produce leaders that exhibit a high degree of operational adaptability (*2*). Additional documents (*3–8*) address the Army training challenge, training gaps, and the conceptual foundation for future leader development education.

The operational considerations combined with the future vision for Army training and the capability and technology gaps create a comprehensive target for Army Research and Development. This target focuses on developing technologies that can

- accelerate learning while increasing effectiveness and efficiency;
- enable learning at the point of need rather than in fixed locations, such as schoolhouses;
- be embedded in the weapon system;
- immerse the Soldier in a cognitively and physically stressful environment;
- replicate the operational complexities of FSOs;
- sense the learner's willingness to learn and adapt to the Soldier's learning needs;
- have an intelligent and engaging interaction with virtual humans as if they are real; and
- be authored quickly to adapt to the rapidly changing conditions.

One must appreciate the complexity of the operational environment. It takes place in the vast context of a host nation and multinational and interagency frameworks that require their own training and leader competencies. This requires a fundamentally different approach to training and learning as Soldiers continue to engage with complex equipment and new threats. As a result, immersing Soldiers in training that focuses on achieving a cognitive and affective level of proficiency will be maximally effective in completing operations in a smooth and efficient manner, especially when operating in one-on-one interactions.

Cognitive and affective training is different from the psychomotor training that dominated the Army for decades; Soldiers today use psychomotor training to gain knowledge, comprehension, and application, but today's training falls short in preparing Soldiers to analyze, synthesize, and evaluate the operational environment and all that it entails. Cognitive and affective training—which emphasizes evaluation, pausing for analysis and thought, or seeing the entire picture—is a different training paradigm that lacks the specifics needed for Soldiers in the field. In order to rectify these potential deficiencies, the following technologies are example methods proposed to address this fundamentally different approach to training and learning.

2.1 Virtual Humans

Research is being conducted to develop virtual humans that have the ability to act, react, and counter react to verbal and nonverbal stimuli. Virtual humans will need the same level of fidelity as an avatar controlled by a human, use natural language processing, be reprogrammable to adopt different identities (e.g., provide cultural fidelity), and have appropriate facial expressions and gestures. Virtual humans must also respond based on the situation and be capable of showing emotion. Well-developed and economically feasible virtual humans are needed to populate large-scale simulations with credible human models, without increasing human support, thus reducing training support costs. These simulated environments can then be used as interactive training paradigms for Soldiers, in preparation for a particular culture or anticipated style of interpersonal interaction. Even though many of the goals of virtual humans are long term, today we can find the application of virtual humans in various programs. For example, virtual human technology has been integrated into the Electronic Warfare Tactical Proficiency Trainer and the Bilateral Negotiation Simulation. Most of the short-term applications help prepare Soldiers for the complexities of one-on-one interactions, while long-term applications look at one-to-many and many-to-many.

2.2 Adaptive Tutors

Adaptive computer-based tutors could provide tailored training to Soldiers whenever and wherever the need for training arises. That is, training at or near the point of need, limiting the human personnel necessary for proper preparation for a new environment. An ideal adaptive tutor would be as effective as human counterparts and could support pedagogical methods to optimize learning outcomes (e.g., performance, comprehension, retention). By modeling the cognitive and affective states of individual Soldiers, adaptive tutors will be able to adapt instructional content and pace to match the capabilities of the Soldier. Developing artificial intelligence (AI) technology (tools and methods) is essential to accurately model the learning state of the Soldier (e.g., frustrated, confused, engaged), to select the best learning strategies (e.g., feedback, reflection, hints), and to optimize reuse of instructional content.

Major benefits of adaptive computer-based tutoring systems are that they offer more efficient training targeted to areas of weakness. This training can be enhanced by the use of “intelligent” agents to perceive learner attributes (e.g., competence) and tailor training to their most urgent needs. Today’s tutors are limited to very specialized, well-defined domains (e.g., mathematics, physics) and are generally difficult to reuse in other domains because of their handcrafted nature. The long-term goals of this program would be to provide one-to-one and one-to-many adaptive training experiences that are both cost effective and efficient in large distributed organizations like the Army, that are as effective as human tutors, and that support automated development and a high degree of reuse across training domains and populations.

2.3 Dismounted Soldier Training and Mixed Reality

Programs are already underway at the Simulation and Training Technology Center, which consist of the research and development of software and hardware to immerse individual and small groups of dismounted Soldiers into virtual and mixed reality environments. This has the goal of supporting natural interaction between the virtual environment and the Soldiers; for example, support of natural Soldier locomotion (including arm and hand gestures) at a low cost and with little infrastructure is necessary in order to truly simulate environments in an efficient manner. In the shorter term, one approach (virtual reality) is for the participant-observer to be totally immersed in, and able to interact with, a completely synthetic world. This approach looks at the integration of the Soldier into a virtual reality environment through the use of helmet mounted displays, sensors for tracking Soldier/weapon movement and locomotion, image/signal processing algorithms, and embedded computer/RF systems. The longer-term approach (mixed reality) looks to merge virtual entities into the real world to produce new environments where physical and digital objects co-exist and interact in real time. Both approaches intend to produce re-configurable environments for Soldiers to rehearse and train in physically and cognitively stressful, virtual operational environments.

As mentioned previously, our Soldiers must continually interact with their surroundings and the civilians within the areas which they occupy. This is especially the case at the level of the individual dismounted Soldier, who may be in daily or continual contact with foreign cultures and any number of potential adversaries at the interpersonal level. Proper training is tantamount to elicit adaptability and reliable, accurate, and proper performance under pressure. Through use of the exemplar technologies described previously, Soldiers can be better prepared for those situations that might otherwise catch them off guard.

3. Predictive Technologies

Computers affect almost every aspect of the dismounted Soldiers' lives, performing critical functions in diverse areas including education and training, medicine, operations, and downtime activities. The importance of computers in our Soldiers' lives makes human-computer interaction one of the most critical factors in systems design. One fundamental issue in human-computer interaction is that the communication between humans and computers is limited. Over the past decades, tremendous advancements have pushed the bounds on these limitations through the following developments:

- Novel devices to improve information flow into the computer via multimodal devices (*9–11*).
- Collaborative performance among groups of people (*11*).

- Eye trackers (*12*).
- Speech and language (*13*).
- Touch screens, gesture and motion capture (*14*, *15*), and facial expression recognition (*16*).
- Computers that provide more useful, relevant, or realistic information back to the user through improved visual displays and graphics, tactile and haptic feedback (*17*, *18*), three-dimensional audio (*19*), and virtual reality (VR) environments (*20*).

In addition, improved algorithmic approaches for predicting human behavior and intention, such as collaborative filtering (*21*), physiological computing (*22*), affective computing (*23*), user modeling (*24*, *25*), and player modeling (*26*), open up the possibility of adapting devices to users and their needs.

While these steps have increased the quantity, quality, and interpretation of information transferred between the human and the system, human-system interaction is still fundamentally bounded by the inherent capabilities of humans to absorb, analyze, store, and interpret information to create behavior, and by limitations in the ability of computers to understand humans and what they are attempting to do and communicate. However, the tremendous growth of research in interpreting and predicting human behavior over the past several decades offers an approach to address these limitations. This research offers many potential insights into the mental processes of the human—insights that could potentially expand the current fundamental bounds on human-computer communications and open the door to completely novel approaches to both human-computer and human-human interaction (*27*, *28*). Here, we focus on predictive technologies and discuss how such technologies may influence our future dismounted Soldiers.

Among the most revolutionary types of technologies currently being developed are those that enable computers to predict or infer what users are attempting to communicate. Such technologies range from search engine technologies that use collaborative filtering to suggest search terms (such as Google Auto-Complete) (*21*) to brain-computer-interaction technologies (BCITs) that translate neural signals to rapidly identifying targets or generate novel communications (*29–31*). For example, Google's search engine leverages massive databases of past user behavior to construct filters or models of user behavior from across the world. It then integrates a user's past history with the filters developed from another user's past behavior to develop an individualized user model. The results of this process are remarkable; repeat users of the search engines often need to enter only a few letters to have the search engine accurately predict search terms and even entire search phrases. While predicting a few search terms may seem trivial, it demonstrates that these technologies can make connections that span not only words, but also time and even individual users.

It is not hard to envision technologies that will allow users to input several sets of words or concepts and return novel concepts or ideas. While being driven largely by the advertising industry, these base technologies already enable the computer to predict the desires or need of users and have expanded well beyond the search engines and into many hand-held and desktop applications. As we look further into the future, such technologies could be a fundamental component underlying human-system communication, hence influencing human-human comprehension. For example, an "overseer" computer might analyze the ideas or concepts from multiple people who are communicating and suggest communications to a specific user or to the entire group that would facilitate conversation.

Over the longer-term, BCITs are envisioned that will further augment the ability to predict human intention and behavior. As human-computer interfaces expand beyond mouse, keyboard, video screen, and speaker interfaces into natural user interfaces, the bandwidth between human and computer will increase. One of the breakthroughs of natural user interface concepts is the idea that in face-to-face human communication, much more information is transmitted than just the words being spoken, but other information, such as body language, facial expressions, and vocal inflections, all add to the meaning of what is being communicated. BCITs extend this concept further by providing additional insight into the neural state of the operator; this insight offers additional contextual information to augment human-computer communication. For example, neural signals have been used in the advertising domain for gauging and understanding the responses of consumers to different products (*32*). BCITs using the real-time detection of emotions, frustration, or surprise (*33*) could enable training or educational applications to adapt in ways that could enhance the learning rates of the students (*34*). Further, advanced BCITs that combine multiple sensor systems, such as eye- and head-tracking with brain imaging, are envisioned that can estimate not only which display the user is looking at (*35*), but also other factors that will influence the capabilities of the user, such as user attention location and level (*36*), fatigue level (*37*), and arousal levels (*38*). Such technologies could combine these estimates to generate probabilistic predictions as to the user's processing of available information, which could then be used to alter the information displays to enhance the effectiveness of the communications bandwidth.

Taking these concepts a step forward, BCITs may even predict aspects of the user's comprehension of the information. For example, there are neural signatures (N400) that indicate whether a word in a sentence is perceived by the user as semantically correct. Based on this, a device might track the incidences of semantic misunderstanding in a conversation, be it peer-to-peer, student-to-teacher, or even human-to-computer. With this type of information, systems are foreseen that can provide general indicators of comprehension or communication efficiency between parties. Further, systems could cue users to repeat or rephrase conversations or even to suggest alternatives to wording that was ambiguous, misleading, or incorrect. For example, social BCITs that combine such comprehension systems with emotional cues from an audience could aid in the crafting of public speeches, advertisements, and movies. For further information on our vision of future BCITs, please see refs. 39 and 40.

Over the near and far terms, the predictive technologies just discussed are expected to make wide-ranging impacts on training and education, home and entertainment, medicine, and work.

While these technologies will undoubtedly reach our dismounted Soldiers, these same technologies can enable an overmatch for our Soldiers against adversaries who are not equivalently equipped. Applying this technology to Army needs will require the compilation of databases of relevant information (e.g., linguistic corpuses, imagery, typical lifestyle habits, local customs) of other cultures and arranging them into useable formats; however, this technology and information either already exists or can be easily compiled. By streamlining the flow of information to include only what is most relevant to the situation, our Soldiers can be better prepared for scenarios that might be otherwise ambiguous and confusing. Maximizing uncertainty is a common tactic in warfare, especially against foot Soldiers; thus, predictive technologies will provide Army personnel an additional unexpected advantage against an opponent relying on such tactics.

4. Human-Automation Interaction and Interfaces

Automations such as robotic devices and other intelligent systems are quickly becoming a prevalent part of the battlefield and are being integrated into the operations of Soldiers on the ground. As tools, these devices can greatly enhance the capabilities of a Soldier or squad by performing operations that are either unsafe or simply impossible for humans. However, as such automations become more prevalent in the battlefield, it is important to design the Soldier-machine interfaces (SMIs) in ways that will enable effective and efficient Soldier-automation teaming and interaction. In future battlefields, the capabilities of intelligent systems will become more effective and efficient, and require less manual control from the Soldier operators; however, these systems will inevitably come with cognitive costs as well as benefits. In order to achieve battlefield efficiencies, a single Soldier will supervise multiple systems that will not require individual attention under normal circumstances. One must be careful, however, because management of several devices could easily overwhelm the Soldier operator during the "heat of combat." In particular, the Soldier's situational awareness (SA) and understanding of system states could suffer from poorly designed automation (*41*, *42*). Therefore, effective SMI designs that promote Soldier SA and understanding will be a vital element in future Soldier mission successes (see a detailed review in ref. 43).

The following sections outline several areas that have already received extensive research and could yield impact with a fairly minimal investment.

4.1 Multimodal Displays and Controls

These displays and controls can promote Soldier SA by providing effective cueing and head-up modes of operations. The Soldier's attentional focus will be limited if all information is delivered through a single modality. That is, simply projecting text or images onto goggles or a helmet screen will yield only minimal gains while pushing the visual system beyond capacity.

Rather, information provided to otherwise unused senses is more likely to be efficiently processed. For example, tactile and voice systems have been used successfully to augment the visual channel for attentional cueing, tactile vocabularies (e.g., Army hand signals), and navigation aids. Additionally, tactile signals will be particularly useful for covert communications with robotic systems and voice systems for "hands-free" limited natural language dialogues with intelligent systems. Also, multimodal systems are a potential research avenue for increasing cognitive bandwidth in multitasking environments (*44–46*).

4.2 Attention-Management Tools (Interruption Recovery Aid)

When controlling multiple systems at the same time, the operator will inevitably tend to some aspects of the environment (e.g., one of the systems) before continuing to monitor all the systems. Techniques that facilitate task resumption have been proposed and tested in various tasking environments. Some techniques focus on reminding the operator where he was before the interruption, while others present aids for the operator to quickly review what happened during the interruption (by text and/or video).

In the far term, the following areas will likely provide fruitful results.

4.3 Flexible Automation

Flexible automation protocols will permit dynamic tasks to be relocated as a function of changes in mission parameters that can cause overload or unsafe conditions. In mixed initiative systems, safety procedures can be invoked if the Soldier cannot respond to a dangerous event. Adaptive systems can modulate the workload given to an operator during mission segments requiring multitasking, using information gleaned from neurophysiological indices (such as the BCIT methods described previously) or preauthorized event triggers. Soldier-authorized adjustable automation can be used to give the operator control of what and when to automate multitasking functions (*42*, *45*). While the precise implantation and invocation methods are still a matter of research and will probably be task-specific, the increased flexibility of such systems has high-potential payoffs for Soldier safety and enhanced performance.

4.4 Trust Calibration Tools

As automated capabilities become more prevalent in the battlefield, it is important to make the automation more transparent (behaviors, capabilities and limitations, reliability, etc.) to the Soldier users in order for them to calibrate their trust in the systems appropriately. Additionally, the system should enable the user to query the automation in an efficient and intuitive manner, to inspect raw information sources when necessary, and to verify or negate the automated advice.

4.5 Intelligent Agents

As the number of automated systems that Soldiers must operate increases, it will be beneficial to investigate the utility of creating intelligent agents that help Soldier operators coordinate and supervise those systems. In such a scheme, instead of directly managing each individual system, the human operator deals only with one single entity, the intelligent agent. This allows the operator to better focus on other tasks requiring his attention. U.S. Army Aviation and Missile Research and Development Center has started to develop systems with similar capabilities (e.g., the Playbook agent for multiunmanned aerial vehicle management) (*45*). Advances in AI will likely allow the operator to apply such agent capabilities to ground operation domains and to enable more fluid interaction between the operator and the agent than following predetermined "plays" and scripts.

All together, the goal is to ensure improved efficiency for Soldiers as they interact with and control increasing numbers of complex devices. While the devices themselves have the potential to provide a clear advantage over our adversaries, these advantages can be realized only with proper design of the means in which the operator must interact. In fact, carrying over known models of how humans naturally divide SA can make these interactions maximally efficient.

5. Technologies to Enhance Sensory Awareness

Extending a dismounted Soldier's physiological sensing capabilities beyond his natural boundaries could provide an overwhelming advantage on the battlefield; for example, increasing the quality of information coming into a Soldier's natural hearing and sight would yield a time and range advantage over the enemy before engaging in combat. Often the limiting factor to dominating a fire fight is how well the enemy can be detected (seen and heard) and, conversely, how effective the enemy is in detecting, identifying, and targeting our Soldiers.

As an example, localizing a gunshot sound is normally a difficult task because of differences in the direction of the muzzle blast and shock wave combined with reflections from surrounding structures and terrain features. Systems for detecting and locating the source of small-arms fire have been in use for over a decade in many urban environments (*47*, *48*). Vehicle-mounted systems have recently been fielded; however, the current models are large, bulky, and impractical for discrete mobility. In the near term, the development of compact and portable models that are built into enhanced body-worn detection systems would greatly improve a dismounted Soldier's ability to determine the source of small arms fire.

A steerable spatial beamforming microphone array is another acoustic sensor system that is nearing maturity for practical application on the battlefield. Beamforming is a technique of localizing the source of a signal by combining across an array of sensors. The Navy has successfully used this technology in sonar systems for decades; however, the size and weight have made such systems impractical for dismounted Soldier applications. When applied to a microphone array that can be much smaller and more portable, the possibilities increase dramatically. In fact, beamforming microphone arrays are already in use in hearing aid and teleconferencing systems. These small and lightweight systems could be adapted for practical body-worn applications and could complement sniper detection systems. For example, a sniper detection system might identify the location of a small-arms fire event. The Soldier could then use a steerable beamforming microphone array to scan the area around the indicated sniper location to listen for enemy movement, voice communications, and other acoustic disturbances. Such passive arrays could aid the Soldier by amplifying otherwise inaudible sounds. Additionally, active high-power ultrasound motion detectors could indicate enemy activity, even when such movement does not produce audibly detectable sound energy.

The ability to interpret radio communications could be greatly improved through the spatial distribution of different sources across virtual space. With current systems, when multiple audio feeds occur, they are overlaid within a single channel; this leads to confusion and difficulty mentally segregating signals (*49*). Rather, using virtual spatializing technology, signals could be presented to different "locations" within the auditory scene, enhancing stream segregation and making it easier for the listener to hear what was being spoken (*50–52*). Binaural radio systems currently exist from Telephonics and Palomar Corporations for airborne applications, and digital radio simulators, such as ASTI, currently have spatial audio capability. Tactical radios, such as JTRS and QNT radios, are starting to provide GPS location information embedded in the radio signal. Thus, in the near term, these technologies could be combined, so the direction of a communication source is presented in an analogous spatial format to the receiver.

Tactile and bone conduction transducers can display vibratory information to the Soldier without impeding the natural functions of his eyes or ears. Vibration and infrasound sensors to detect below ground activity and movement of enemy personnel could be displayed to tactors on a Soldier's boots, indicating extraneous vibration due to ground-based activity. Additionally, speech communications from radios could be displayed through bone conduction vibrators located on the skull to utilize bone conduction pathways to the auditory system without having to occlude the ears, which often makes Soldiers uncomfortable because of lost external awareness (*53*, *54*).

After exposure to very loud weapons fire, Soldiers experience a temporary deafness called a temporary threshold shift. Protecting the ears from high intensity impulsive sounds would maintain the very high sensitivity of our auditory system. This would provide our dismounted Soldiers a great advantage over an adversary who was not protected from loud sounds and is experiencing an elevated hearing threshold. Someone with a temporary threshold shift would need to talk louder or yell to be heard by comrades and would be less aware of nearby sound-producing events. A high-performance, nonlinear hearing protection device would provide this advantage. Although several such devices have been developed and are currently in use, Soldiers often choose not to use them because they decrease hearing at normal levels, making them feel less aware of their surroundings (*53–55*). Ideally, such nonlinear hearing protection devices would not cause attenuation at low sound levels, nor would they disrupt normal voice communication and auditory localization abilities; however, they would attenuate all loud impulse noise to a safe level.

In the longer term, an analysis of the surrounding auditory environment could be pre-processed for anomalous activity. This will require establishing a database of normal auditory scenes through previous recordings, remote sensing, historical information, and cultural knowledge, analogous to those already in use for visual scenery. A comparison to the current auditory scene would be made, and outlying objects and sounds, or missing activity, could be automatically identified and displayed aurally or visually to the dismounted Soldier. Note that the databases used for this purpose would likely overlap those developed for the BCIT approaches described previously.

Within the visual realm, augmented visual displays would help reveal objects that would otherwise be undetectable by natural vision. Two classes of such objects are those beyond the Soldier's line of sight and those obscured or camouflaged so as to render them effectively invisible to the unaided eye. Applying advanced electro-optical sensors, image processing, and augmented reality would greatly aid the dismounted Soldier in the successful engagement and defeat of both classes, including during night operations when our Soldiers have long possessed a technological advantage.

Acquiring targets beyond line of sight (BLOS) at a high level (i.e., recognizing and identifying them [see discussion on human automation in section 4]) could be enabled by advanced aerial sensors and image-processing algorithms. Unmanned aerial vehicles (UAVs) and satellite imagery could provide a platform for such sensors that could be controlled by the Soldier on the ground when he requires information on potential enemy activity BLOS but still possibly within the range of squad weapons. Additionally, information from sensors not under direct control of the Soldier could be "pushed" to him through an information network should enemy presence be indicated.

Imagery from these UAVs could additionally be sent wirelessly to Soldiers fitted with ballistic and laser-protective eyewear that contains or is itself a screen on which images and information can be projected. Images visible through the eyewear would be augmented by imagery created by the UAV surveillance platforms described previously. In addition to augmenting a Soldier's naked-eye view of the scene with imagery and information from UAVs, the Soldier would also be equipped with advanced electro-optical devices that combine intelligence and information (I^2), IR, and enhanced dynamic range capabilities in order to render otherwise obscured or invisible features of the local scene (within line of sight) visible. These devices would also be capable of receiving additional information from UAV surveillance platforms to augment the scene presented to the Soldier.

Altogether, the combined use of enhanced visual and auditory sensor information will ensure the superiority of the Soldier's performance on the battlefield through heightened total SA. The inclusion of information from auditory sensors serves as an indicator of where to orient both

Soldier- and UAV-based visual sensors. Such notification could occur through a combination of auditory, overlaid-visual, or tactile signals so as to provide both salient notification of a potential enemy location and specific information ready to combine with imagery. Enhancing the natural detection capabilities of the "Soldier sensor" while effectively combining them with intelligent remote sensor systems will provide our Soldier unmatched SA on the battlefield of the future.

6. Whole-System Design Technology

Technology designed to enhance Soldier performance can enhance performance in one area while unintentionally sacrificing performance in another. For instance, a new weapon sight may enhance marksmanship performance while the weight of the new sight causes the Soldier to move more slowly, thereby negatively affecting overall performance. Or, new communication devices may provide Soldiers with better information that allows them to make better decisions; however, the user interface could be more complex, the device itself could be heavier, or the placement of additional equipment could make it difficult to use. As another example, while personal protective equipment (PPE) offers Soldiers greater protection, many times PPE inhibits overall performance. Hearing protection that is designed to protect Soldiers from potentially injuriously loud noise simultaneously prevents the user from hearing soft noises in the environment, decreasing the ability of the Soldier to spatially locate the origin of sounds. For this reason, Soldiers often choose not to wear the protection at all. Likewise, body armor is designed to enhance Soldier survivability, when in fact the weight and location of body armor inhibit mobility, which in turn increases exposure time and may actually decrease survivability. One underlying cause for this is that most Soldier equipment is designed to a performance specification for the *equipment*—not a *Soldier performance* specification.

A solution to this problem is to develop and incorporate a design methodology that focuses on mission-based operational performance of the Soldier as a primary performance metric, with this approach incorporated into the acquisition cycle. A necessary part of this solution would be to incorporate manpower and integration (MANPRINT) earlier in the process of developing equipment. However, merely moving this within the design process is insufficient. While there are sufficient data on the effects of Soldier equipment on performance of Soldier tasks in a laboratory, there is a dearth of research on the effects of Soldier equipment on realistic operational performance. Also, there is a lack of technology that would enable this research. Many data collection systems are cumbersome and limit Soldier performance in some way. Finally, many operational performance metrics are likely mission specific and, as such, are highly variable.

However, even with this variability, there may be some metrics that can be generalized across missions and used to predict mission success. It may also be possible to use these metrics in predictive models to analyze alternative courses of action (COAs) and then choose the COA that increases the potential for mission success. For example, a candidate performance metric may be the amount of time it takes a Soldier to make a decision, as well as the quality of that decision. As combat stress during a mission increases and decreases, so may the ability of a Soldier to make quick, high-quality decisions. With the correct technology, tests can be incorporated into standard Soldier tasks that determine "real-time decision-making ability." The information from these tests can, in turn, be used to evaluate the overall efficacy or influence of a candidate piece of equipment. However, the technology must allow this test to be seamless to the Soldier and provide an evaluator with information on that Soldier's ability to continue performing at a high level, such as real-time monitoring of physical and cognitive performance. Physiological monitoring, which would not require any additional feedback or action on behalf of the Soldier, may provide some useful information, but this information likely needs to be augmented with information on the Soldier's performance. For example, with the Warfighter Physiological Status Monitoring Science and Technology Objective, the U.S. Army Medical Research and Materiel Command has been developing a monitoring system for measuring specific aspects of the Soldier's current physiological state. This system can be used for evaluating not only the current medical status, but also the overall potential effectiveness of the Soldier.[*]

In short, technology needs to be developed that allows for the noninvasive collection of mission-critical Soldier performance (as opposed to physiological) data in operationally relevant environments. This data can be used to monitor Soldier performance, predict future performance, and determine the *real* cost/benefit of candidate equipment prior to full-scale deployment. An example technology for monitoring cognitive performance would be a device that monitors the Soldier's environment, his target task, and his reaction to it. When the reaction is no longer appropriate for the environment, the system could indicate that the Soldier's performance has been decremented. An example technology for monitoring physical performance may be a sensor the Soldier wears that monitors movement patterns during walking. The ankle transcribes a very consistent pattern during walking. While some variability (due to uneven terrain, for instance) is expected, changes to this pattern over time may indicate physical fatigue. When the system detects changes that are too extensive, it could notify the commander that the Soldier is becoming fatigued. Changes in the level of fatigue might be a candidate means for evaluating the impact of candidate equipment.

Together, these examples are provided as illustrations of ways in which the developmental process can be improved to maximize the final effectiveness of a candidate system. The goal is to consider all possible implications of using new devices and how they might impact total mission efficacy. In order to achieve these goals, we need to enhance the current methods of device evaluation, including tools that are transparent and functionally noninvasive to the Soldier, such as monitoring physiological and behavioral metrics of performance. By improving the overall efficiency of the devices Soldiers wear and use, we will inherently maximize how

[*]For more information about Warfighter Physiological Status Monitoring, see https://momrp.amedd.army.mil/pm3.html.

well they operate in the field, further facilitating the goal of an overmatching scenario against an adversary who might not be as well equipped.

7. Summary

We have provided here some example technologies that will directly affect Soldiers and how they interact with the equipment they use. While all of the topics discussed here have implications across a wide range of domains, they are particularly important for the performance of dismounted Soldiers, as they operate either alone or within small groups, and provide several opportunities for overmatch against foes. For example, being able to better sense assailants in combat situations can allow Soldiers to remain a step ahead of adversaries, improving survivability and chances of mission success. This is particularly advantageous in the dismounted scenario, where physical protection is limited. In a similar vein, dismounted Soldiers are often in direct contact with local civilians, either in one-on-one or group situations. Such interactions have the potential to become highly volatile and can be very stressful for the Soldier; technologies decreasing this stress level are inevitably beneficial. For instance, the advanced training techniques described previously will help ensure the Soldier responds in the most appropriate manner, while a BCIT stress-monitoring system will aid in maintaining awareness of how well they are actually handling the situation. In both cases, this leads to an increased comfort level for the Soldier, heightening performance and increasing leverage over an opponent who might be less prepared. Taken together, we feel these are areas where there is high potential for impacting the performance of our Soldiers in a positive manner. While the examples provided here are by no means exhaustive, all may substantially influence the design of future systems.

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